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A Late Miocene acceleration of exhumation in the Himalayan crystalline core

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Abstract

Unraveling the relative roles of erosion and tectonics in shaping the modern topography of active orogens requires datasets documenting spatial and temporal patterns of exhumation, surface uplift and climatic forcing throughout orogenic growth. Here we report the results of biotite $^{40}Ar/^{39}Ar$ incremental heating and single-grain laser-fusion experiments from a nearly vertical, ~1000 m age-elevation transect in the central Nepalese Himalaya. Age-elevation relationships constructed from these data suggest very slow cooling in this part of the Himalayan crystalline core during the Early Miocene, accelerating to only moderate rates at ~10 Ma. If we assume purely vertical exhumation and a steady-state thermal structure, the exhumation rates implied by these data are ≪0.1 mm/yr prior to 10 Ma and ~0.5 mm/yr from ~10–7 Ma. The acceleration in cooling rate at 10 Ma requires a change in kinematics that may be linked to large-scale changes in climate, or to more local tectonic perturbations. Although we do not presently have enough data to assess the relative roles of regional vs. local drivers, these data provide a new constraint on exhumation through the Miocene that must be honored by any model of Himalayan evolution.

Keywords: Himalaya; argon thermochronology; tectonics; climate

1. Introduction

The central Nepalese Himalaya reflects extremes in both tectonics and erosion: a series of thrust faults at the base of the range accommodates approximately 20 mm/yr of convergence between India and Eurasia, while the South Asian monsoon drops over 3 m of rain along the rangefront in a typical season (e.g., Bookhagen and Burbank, 2006). Because the tectonic and climatic signals are both strong in this region, the Himalaya has become a centerpiece in the debate surrounding the degree to which climate and tectonics may be coupled at the orogen scale (e.g., Burbank et al., 2003; Thiede et al., 2004; Wobus et al., 2005; Huntington et al., 2006). Most of these studies cite thermochronologic datasets in which spatial or temporal changes in cooling ages are used as proxies for spatial or temporal changes in exhumation over Pliocene–Recent timescales. However, the strongest climatic signal to have affected the Himalaya is likely to have occurred much earlier (>20 Ma) when recent evidence suggests that South and East Asian monsoon climates were established (Sun and Wang, 2005; Clift, 2006). In addition, a variety of evidence suggests there were substantial shifts in both climate and tectonics in the region in the Late Miocene (~8–10 Ma) (e.g., Kroon et al., 1991; Molnar et al., 1993; Garzione et al., 2000). Pinpointing the timing of such regional "events" – and understanding the degree to which large climatic changes influence local and regional tectonics – requires an orogen-wide database documenting changes in exhumation rates through this period.

Toward this end, we report here the results from a new $^{40}Ar/^{39}Ar$ age-elevation transect in the Langtang valley of central Nepal, documenting cooling of the Greater Himalayan Sequence through the ~350 °C isotherm. Our data include

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single-grain laser-fusion and bulk incremental heating analyses of biotites from the Greater Himalayan sequence, which represents the metamorphic core of the Himalaya. This new dataset is one of the few available that allows direct estimates of cooling rates and patterns in central Nepal through the Miocene (e.g., Vannay and Hodges, 1996; Huntington et al., 2006). As a result, our data provide much-needed constraints on the tectonic evolution of the Himalaya that must be honored by any conceptual or numerical model of early Himalayan orogenesis.

2. Background

Convergence between India and Eurasia – currently estimated at approximately 20 mm/yr based on geodetic observations (Bilham et al., 1997) – is accommodated along the Main Himalayan Thrust (MHT), which represents the main décollement separating the two plates. While the exact subsurface geometry and the timing of activity on surface thrusts remain the topics of active research (e.g., Lave and Avouac, 2001; Wobus et al., 2005; Bollinger et al., 2006), there is general agreement that the MHT splays into three major surface thrust systems to the south of the High Himalaya (Fig. 1) (Hodges, 2000). Of these, the northernmost structure – referred to as the Main Central Thrust system (MCT) – represents the most prominent metamorphic transition, separating primarily greenschist facies rocks in the footwall from amphibolite and higher grade rocks in the hanging wall. Where the MCT is well mapped, it is characterized by a broad (~1 km) shear zone, with evidence for Pliocene to Quaternary brittle deformation in many locations, including in the Langtang valley (Macfarlane et al., 1992; Hodges, 2000; Hodges et al., 2004). In tectonic models that invoke a coupling between focused erosion and extrusion of a low-viscosity “crustal channel”, the rocks in the hanging wall of the MCT – referred to as the Greater Himalayan Sequence (GHS) – represent the exhumed remnants of this extruded channel (Beaumont et al., 2001; Grujic et al., 2002). An alternative model of Himalayan tectonics that calls upon tectonic underplating and duplex formation to grow the high range has also been proposed (e.g., Robinson et al., 2003; Pearson and DeCelles, 2005; Bollinger et al., 2006). Due in large part to the lack of complete cooling histories for rocks from the GHS and the underlying Lesser Himalayan Sequence, either of these models can be shown to be consistent with available data (Wobus et al., 2006) — although the latter model requires a more restrictive set of parameters. Building a more complete exhumation history of the GHS is therefore an important prerequisite for understanding how the central Nepalese Himalaya evolved between the Early Miocene and the present.

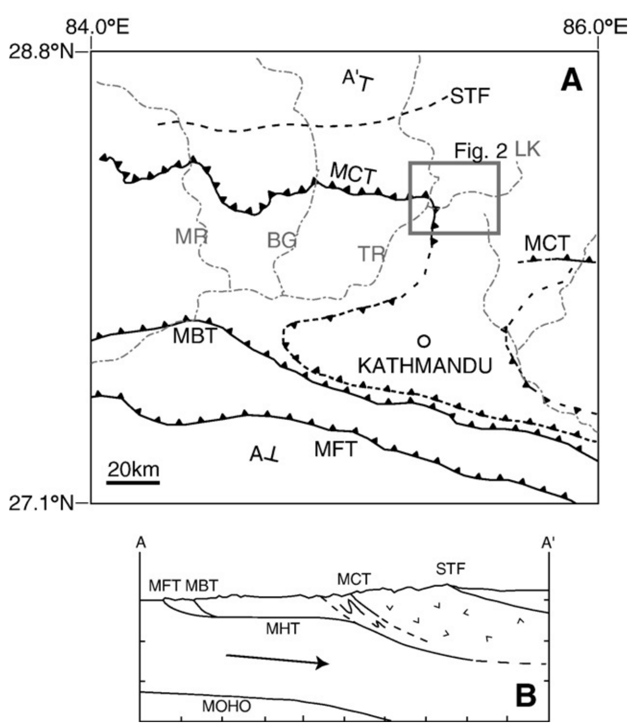

Fig. 1. Regional tectonic setting. A) Location of major thrust systems in central Nepalese Himalaya. MFT = Main Frontal Thrust; MBT = Main Boundary Thrust; STF = South Tibetan Fault system. Grey dash-dot lines are major rivers for reference: LK = Langtang Khola; TR = Trisuli River; BG = Burhi Gandaki River; MR = Marsyandi River. B) Schematic cross-section through central Nepalese Himalaya, showing relationship of surface thrusts to Main Himalayan Thrust (MHT). Patterned region between MCT and STF is Greater Himalayan Sequence (GHS). Figure adapted from Wobus et al. (2005).

Available geochronologic data from the GHS in Nepal and India typically indicate cooling of this metamorphic core through ~350 °C in the Early–Middle Miocene (e.g., Hubbard and Harrison, 1989; Copeland et al., 1991; Macfarlane, 1993; Vannay et al., 2004). In general, these inferences are based on results from individual bedrock samples, and therefore do not yield insights into the temporal patterns of exhumation in the GHS through this interval. One pattern that consistently emerges from previous geochronology on the GHS, however, is a general younging of cooling ages structurally down-section within ~5–10 km of the MCT (Hubbard and Harrison, 1989; Copeland et al., 1991; Macfarlane, 1992). $^{40}Ar/^{39}Ar$ cooling ages as young as the Late Pliocene (~2–3 Ma) have been documented from within the MCT zone in the nearby Marsyandi valley (Edwards, 1995), and in the Langtang valley (Macfarlane, 1993). Young $^{40}Ar/^{39}Ar$ cooling ages such as these are generally interpreted as reflecting either out-of-sequence brittle motion within the MCT zone (Macfarlane, 1993; Hodges et al., 2004), or late-stage hydrothermal activity within the MCT zone (Copeland et al., 1991) in the Pliocene.

Previous estimates of exhumation rates in the Himalaya are most commonly based on valley-bottom samples and/or low-temperature thermochronometers. As a result, these datasets typically require some assumptions about the thermal structure of the upper crust, and provide information on exhumation rates only since the Pliocene. Estimated Pliocene–Recent exhumation rates commonly exceed 2 mm/yr based on low-temperature thermochronology (Sorkhabi et al., 1996; Burbank et al., 2003; Thiede et al., 2004). An age-elevation transect in the nearby Marsyandi valley suggests considerably slower rates (~0.5 mm/yr) in the Early Pliocene (Huntington et al., 2006), consistent with the average rates that can be inferred from $^{40}Ar/^{39}Ar$ ages of 15–20 Ma commonly reported from higher in the GHS section throughout the Himalayan arc (e.g., Hubbard